Influences of Microbial And Mineral Particles On Oceanic Optics

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LONG-TERM GOAL

The overall goal of this work is to understand in detail how various types of microbial and mineral particles and dissolved substances determine the inherent and apparent optical properties (IOPs and AOPs) of oceanic waters. In particular, we wish to quantify how variability in the detailed composition of oceanic water determines the variability in the IOPs (such as absorption and scattering coefficients) and AOPs (such as spectral reflectance and diffuse attenuation functions). This work is fundamental to the development of bio-geo-optical models for Case II waters, for which the presently available bio-optical models are known to fail.

OBJECTIVES

We seek to answer many questions, for example: (1) In what ways does variability in the microbial and mineral composition of ocean waters determine variability in the IOPs and AOPs of such waters? (2) Is it possible to quantitatively classify the *optical* properties of water using the Case 1/Case 2 scheme? (The Case 1/2 classification is based on water composition; the optical distinction between Case 1 and Case 2 is unclear.) (3) What information about the nature of suspended particles can we hope to extract from remotely sensed signals?

APPROACH

We are using a database of the single-particle optical properties (absorption and scattering cross sections, and scattering phase functions) of different types of microbes (ranging in size from viruses to nanoplankton) and other components as input to radiative transfer numerical models to study the effects of different types of particles on oceanic light fields. This approach gives us complete control in determining the constituents of a simulated water body and in examining the optical influences of different types of particles. The database development is carried out by Stramski, and the modeling is performed by Mobley; both investigators participate equally in the analysis of the results.

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The single-particle optical properties are obtained from a combination of laboratory experiments and Mie scattering calculations (Stramski and Mobley, 1997; Stramski, et al. 1998; see also Stramski's annual report). The single-particle properties are combined with particle concentrations and standard models for dissolved substances to determine the bulk IOPs of a water body. These bulk IOPs are then used as input to the Hydrolight 4.0 radiative transfer model (Mobley, 1998; see also http://www.sequoiasci.com/hydrolight.html). Hydrolight computes the full spectral radiance distribution within the water (including water-leaving radiances and all quantities derived from the radiance, such as irradiances and diffuse attenuation functions). Changes in various light-field quantities (e.g., water-leaving radiances or diffuse attenuation functions) are monitored as the input to the model is systematically varied.

WORK COMPLETED

The database of single-particle optical properties has now been expanded from its original five microbes (as used in the initial simulations of Mobley and Stramski, 1997a) to 24 microbes plus several non-microbial components. The non-microbial components include air bubbles, generic mineral particles (polydisperse particles with a high index of refraction), organic detrital particles (polydisperse particles with a low index of refraction), and dissolved substances. Using this larger database, the preliminary simulations we made last year were recomputed. We completed several hundred Hydrolight simulations using various combinations and concentrations of particulate and dissolved components. Component concentrations used in these simulations ranged from low values characteristic of open ocean waters to high values characteristic of productive coastal waters. Bloom conditions and case 2 waters were simulated. We studied the effects of water composition on both in-water optical properties (such as the scalar irradiance and diffuse attenuation), on the remote-sensing reflectance, and on the point spread function.

RESULTS

The more-realistic simulations made this year strengthen our previous findings (Mobley and Stramski, 1997b). For example, we found that it is not necessary to include each microbial component in order to realistically simulate the optical properties of a water body. For example, it is sufficient to use an "average" or "generic" prochlorophyte and an average *Synechococcus* in simulations. This is not surprising because, for example, different prochlorophyte strains have similar optical cross sections and particle sizes. However, it is *not* possible to define an "average small nanoplankton." This is because the various species of small nanoplankton can have significantly different optical properties and size distributions. However, we do find that the detailed species composition of the small nanoplankton is not crucial, so long as the various-sized particles obey a Junge size distribution overall, with the same total concentration of these particles.

We have found that the simple bio-optical models commonly used for the IOPs of dissolved substances and detritus can have large effects on the remote-sensing reflectance R_{rs}. These models have various parameters whose values are commonly assumed to have "typical" values. However, these parameters can vary widely in magnitude. For example, absorption by detritus is often modeled by an equation of the form

$$a_{\mathrm{det}}(z,\lambda) = a_{\mathrm{det}}(z,\lambda_o) \exp[-\gamma(\lambda - \lambda_o)] . \tag{1}$$

The wavelength reference point λ_o is usually taken to be 400 or 440 nm. Values of the exponent slope parameter γ as reported in the literature range from 0.006 to 0.014, with an average value of about 0.011. Figure 1 shows R_{rs} as predicted for three values of γ. All other parameters of the simulation—the concentrations of the other water components, the sky conditions, the sea state, etc—were held constant. The detrital scattering coefficient was assumed to have a λ^{-1} dependence on wavelength. In the simulations of Fig. 1, the natural variability in γ gave a variability in R_{rs} that was as large as the variability induced by a factor-of-two change in the total microbial concentration. The surprisingly large variability in R_{rs} owing to the variability of the γ parameter highlights the importance of properly modeling all components of a water body, not just the microbial components, even in case 1 waters. Note that, in this simulation, the natural variability in γ gave a difference of over 30 per cent in the ratio $R_{rs}(415)/R_{rs}(485)$. Such ratios are commonly used in extracting information from ocean-color remote sensors. Indeed, we believe that organic detritus deserves much more research attention.

Although the literature contains measurements of the point spread function (PSF) in various waters, very little work has been done on understanding variability in the PSF. Note,

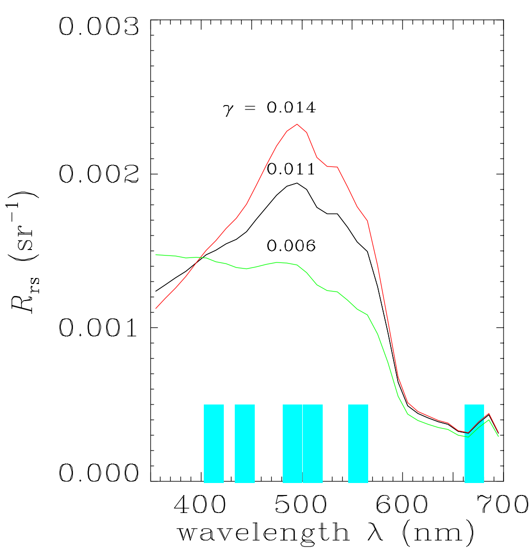

Fig. 1. The effect of the detrital slope parameter γ of Eq. (1) on the remote-sensing reflectance. The blue bars show the nominal SeaWiFS bands.

in particular, that there are no "bio-optical" models for the PSF, because the PSF depends on the entire particle size distribution and not on any one parameter such as the chlorophyll concentration or the total suspended particle load. Our database and radiative transfer models are ideal for understanding in detail how the water composition, including the particle size distribution, determines the PSF. Figure 2 shows examples of the PSF computed for four different water compositions. The PSF was computed using the database as input to a Monte Carlo model (Mobley, 1996). In the first case (black lines), the water had a base concentration of microbial particles and other components, which was chosen to be representative of oligotrophic, open ocean conditions; the chlorophyll concentration was *Chl* = 0.07 mg m^{-3}. The second case (green lines) again used the base concentrations, but increased the concentration of heterotrophic bacteria to simulate bloom conditions. In this situation, the chlorophyll concentration is unchanged, but the water contains many more small (~0.5 µm diameter) particles. The third case (red lines) simulated a bloom of *Synechococcus* (~1 µm); now *Chl* = 0.27 mg m^{-3}. The fourth case (blue lines) simulated a bloom of *Dunaliella tertiolecta*, a small nanoplankton with a diameter of ~8µm; now *Chl* = 3.12 mg m^{-3}. For each case, the PSF is shown at ranges of r = 5, 10, and 20 m. Predicted PSFs such as these allow for the detailed understanding how different substances contribute the the PSF. The PSFs of Fig. 2 are suitable for use as input to performance models of underwater imaging systems, which use the PSF to quantify the effects of the water on image propagation. Additional results are found in Mobley and Stramski (1998).

IMPACT/APPLICATIONS

This work is an important step towards achieving scale closure—the reconciliation of single-particle (small scale) optical properties with the large-scale optical character of the ocean. Achieving a detailed understanding of the roles played by various types of particles and other components on oceanic radiative transfer is a prerequisite to advancing bio-optical models

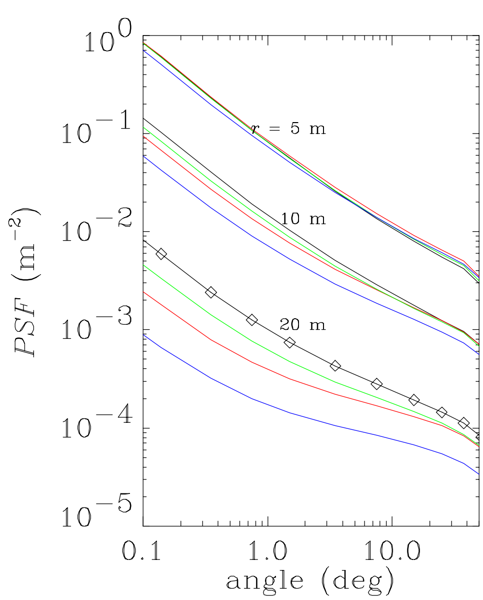

Fig. 2. Example of computed point spread functions. The PSF is shown for ranges of r = 5, 10 and 20 m and for four different water compositons: an open ocean base case (black); a heterotrophic bacteria bloom (green); a synechococcus bloom (red); and a chlorophyte bloom (blue). The diamonds on the 20 m base case show the angular resolution used in the Monte Carlo simulations.

beyond their present one-parameter (the chlorophyll concentration) description of very complicated and variable situations. This work also leads to a quantitative understanding of what information about oceanic particulates we can and cannot expect to extract from remotely sensed signals, which are the basis for "ocean color" assessments of the ocean's upper layer.

TRANSITIONS

As listed in Stramski's annual report, parts of the database have already been made available to several academic researchers, and such requests are likely to increase now that the database is greatly expanded. The point spread function predictions are being made available to M. Strand of the Naval Coastal Systems Station for use in the IMPERSONATOR model, which predicts the performance of underwater imaging systems.

RELATED PROJECTS

This work directly incorporates the database development results described separately by Stramski. The modeling methodology developed in the course of this work is finding wide application in other research projects.

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